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ABSTRACT

Use of beef feedlot waste (FLW) in crop rotations including sugarbeets (*Beta vulgaris* L.) would provide a use for a surplus waste product. Objectives of this study were to assess the effects of FLW on soil chemical characteristics and on sugarbeet yield and quality. Amounts of FLW applied on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) over a 16-yr period ranged from 0 to 1608 Mg ha^{-1}. Retention of applied FLW drymatter (DM) as soil OM ranged from 14 to 2%, N (applied in DM) as total N from 47 to 5%, and P as $NaHCO_3$-extractable P from 18 to 8%. Retention depended on amount and recency of application. Nitrifiable N, determined chemically, was closely associated with OM (r = 0.88), total N (r = 0.93), and with NO_3^--N (r = 0.95). All treatments that had previously received FLW produced significantly higher sugarbeet root and sucrose yields than those that had received N, P, and K plus added N on the sugarbeet crop. Consequently, use of FLW in crop rotations including sugarbeets merits further study. Sucrose concentrations of the sugarbeets were inversely related while concentrations of Na, NO_3, and amino-N in the roots were directly related to soil NO_3^--N and inversely related to sucrose. Nitrifiable N was closely associated with root yield, sucrose yield, sucrose concentration, nitrate grade, and amino-N. Nitrifiable N, as determined in this study, deserves further evaluation as an indicator of N supplying capacity of the soil.

BEEF FEEDLOT WASTE (FLW) is a byproduct of the cattle feeding industry. Although it is good fertilizer for most crops, disposal of the waste is a problem in the southern High Plains of the USA. Large feedlots are in areas of fine textured soils that tend to be well supplied with P and K. Use of the waste as fertilizer requires hauling and handling large quantities and its N fertilizer value is often not competitive economically with inorganic N sources. Large piles accumulate at feedlots because there is little demand for it.

Mathers and Stewart (1984) summarized the results of a 14-yr study in which FLW was applied on Pullman clay loam. Total amounts applied during the 14-yr period ranged from 0 to 1608 Mg ha^{-1}. They found that annual applications of 22 Mg ha^{-1} were adequate for high yields of good quality crops. Higher rates of FLW resulted in high nitrate levels in forage and severely reduced yields when crops were planted before ammonia or salt accumulations had dissipated. Feedlot waste increased soil OM, extractable P, NO_3^--N, and saturated hydraulic conductivity and reduced soil bulk density. The study was conducted for 2 additional years and was terminated.

Sugarbeet is a good plant for assessing the effects of soil treatments on crop quality because root quality is important in sugar production and is affected by element uptake. It is well established that excess N causes reduced sucrose concentration and increased impurities (Halverson and Hartman, 1975; Anderson and Peterson, 1988; Carter et al., 1976). Carter (1986) found that K and Na uptake were affected by N uptake and availability of K and Na. Locally, sugarbeet is grown in 5-yr rotations with other field crops. Questions frequently arise concerning the effects of FLW applied at different times in the rotation on sugarbeet yield and quality.

This study was conducted to further assess the effects of 16 yr of FLW application ranging from 0 to 1608 Mg ha^{-1} on the chemical characteristics of the soil (OM, total N, NO_3^--N, N_o, $NaHCO_3$-extractable P, exchangeable K, Na, Mg) and on yield and quality (sucrose concentration, nitrate grade, amino-N, Na, and K concentrations) of sugarbeets.

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MATERIALS AND METHODS

The site was that of a 16-yr (1969–1984) irrigated field study on Pullman clay loam at the USDA Conservation and Production Research Laboratory, Bushland, TX. Details of the design and results of the study have been published (Mathers and Stewart, 1984). The nine treatments and total amounts of FLW, drymatter (DM) and N, P, K, Na, and Mg applied are given in Table 1. Crops grown were grain sorghum [*Sorghum bicolor* (L.) Moench] for 10 yr, and corn (*Zea mays* L.) and wheat (*Triticum aestivum* L.) each for 3 yr. Treatments were replicated three times in a randomized block design. Individual plots were 8 by 24 m in size. Crops were irrigated as needed for emergence and good growth. The study was terminated in 1984 and the site was fallowed in 1985 to dissipate herbicide residues. In February 1986, composite soil samples (from five locations per plot) were taken by 0.15-m increments in the surface 0.3 m, then by 0.3-m increments to a depth of 3.6 m. Portions of each sample were extracted with 0.1 *M* KCl for determination of NO_3^--N (Kamphake et al., 1967). Remaining portions of each sample were air dried, ground to pass through a 2-mm sieve, and analyzed for total N (Kjeldahl), OM (Jackson, 1958) $NaHCO_3$-extractable P (Olsen and Sommers, 1982), and exchangeable Na, K, and Mg [extraction with 1 *M* NH_4OAc

Table 1. Fertilizer elements applied in FLW during the 16-yr period prior to initiation of this study.

Code	Treatment	Feedlot waste	DM	N	P	K	Na	Mg
		— Mg ha^{-1} —		———— kg ha^{-1} ————				
CHK	Check	0	0	0	0	0	0	0
N	N†	0	0	2 410	0	0	0	0
NPK	NPK‡	0	0	2 410	728	728	0	0
22/13	22 Mg ha^{-1}§	286	179	4 350	1480	3 410	1370	1230
67/13	67 Mg ha^{-1}§	871	537	13 060	4430	10 230	4100	3680
134/5	134 Mg ha^{-1}¶	670	346	10 000	2090	6 600	2770	4070
268/5	268 Mg ha^{-1}¶	1340	692	20 000	4180	13 200	5550	8140
536/3	536 Mg ha^{-1}#	1608	895	26 600	5630	17 960	7560	8040
536/1	536 Mg ha^{-1}††	670	361	12 050	2470	7 960	2710	4070

† 268–0–0 or 134–0–0 applied annually (13 yr).
‡ 268–56–56 or 134–56–56 applied annually (13 yr).
§ Applied annually (13 yr).
¶ Applied annually 1969 through 1973.
# Applied annually 1969 through 1971.
†† 536 Mg ha^{-1} applied in 1969 plus 67 Mg ha^{-1} applied in 1981 and 1983.

and determined by atomic absorption (Knudsen et al., 1982; Lanyon and Heald, 1982)].

Nitrogen mineralization potentials (N_0) were determined from chemical indexes of soil N availability (N_i) as suggested by Stanford and Smith (1976). Stanford and Smith found that the equation $N_0 = 4.1 \pm (1.0)\ N_i + 6.6$ provided a means of reasonably estimating N_0 from N_i. The chemical index was determined by autoclaving the soil for 16 hr at 121 °C and the NH_4^+-N produced was measured by the Conway microdiffusion method (Stanford and Smith, 1976). In a trial study with one replicate of samples, amounts of N nitrified in 12 wk (Stanford and Smith, 1972) and N_i were found to be closely related ($R_2 = 0.86$).

After preplant irrigation (0.09 m), sugarbeets ('Mono-Hy TX 11' pelleted seed) were planted on 27 Mar. 1986. Beets were seeded on 0.76-m spaced beds and were thinned to 5 plants m^{-1} of row at the eight-leaf stage. Best known practices were used for seedbed preparation, weed, insect and disease control, and irrigation. The crop received 490 mm of irrigation water and 480 mm of rainfall between planting and a mid-November harvest. On 13 May, plots were split longitudinally and N (134 kg N ha^{-1} as NH_4NO_3) was applied to the crop on one-half of each main plot. An irrigation was applied on 15 May to move the applied N into the soil.

Sugarbeets were harvested with a mechanical harvester (2 rows, 15 m long). Subsamples of beets were analyzed for brei nitrate and sucrose at the Holly Sugar Co. laboratory, Hereford, TX. Subsamples were frozen and sent to Intermountain Laboratories in Sheridan, WY for analyses for Na, K, and amino-N. Brei nitrate concentration was determined with a nitrate electrode and is reported as nitrate grade (2 + 3.4 log mg L^{-1} nitrate electrode response − 1). Thus, grade is 1 for <10 mg L^{-1} NO_3, 2 at 10 mg L^{-1}, 5.5 at 100, 8.99 at 1000, and 9 for >1000 mg L^{-1}. Sucrose was determined with a polarimeter by the cold digestion method (DeWhalley, 1964), Na and K by flame photometry, and amino-N by ninhydrin (Lawrence and Grant, 1963). Percent sucrose loss to molasses was determined by the procedure outlined by Hilde et al. (1983).

The experiment was not repeated in time because only three replications of FLW plots were available and sugarbeets are not grown in short rotations.

RESULTS

Effects of Previous Treatments on Soil Properties

Results of soil analyses are given in Table 2. The FLW applications increased OM, total N, NO_3^--N, N_0, extractable P, and exchangeable K. Exchangeable Na and Mg were not significantly affected by FLW applications. Proportions of applied DM retained in the soil as OM (calculated from DM applied and increases in OM) ranged from almost 14% on 22/13 [FLW rate (Mg ha^{-1})/number of applications] to about 2% on 536/3. Since the more recently applied DM had less time to decay, one would expect its retention to be greater than that of the earlier applied DM, thus the greater retention on 22/13 and 67/13 than on 134/5, 268/5, 536/1, and 536/3 was expected. However, the greater retention on 22/13 (14%) than on 67/13 (8%)

Table 2. Changes in chemical properties (NO_3^--N, nitrifiable N, OM, total N, $NaHCO_3$-extractable P, and exchangeable K, Na, and Mg) of various soil depths in response to FLW and fertilizer treatments.

	Treatments									
	CHK	N	NPK	22/13†	67/13	134/5	268/5	536/3	536/1	LSD (0.05)
NO_3^--N, kg ha^{-1}										
0–1.8 m	92	129	149	260	357	135	291	404	152	164
1.8–3.6 m	18	58	70	118	195	66	141	172	86	92
Nitrifiable N, mg kg^{-1}										
0–0.15 m	88	–‡	116	195	259	146	223	251	161	61
0.15–0.30 m	57	–	56	69	96	89	130	96	87	NS
0.30–0.6 m	23	–	29	27	35	38	37	48	39	21
Organic matter, g kg^{-1}										
0–0.15 m	18.3	18.9	22.6	29.2	34.8	25.4	30.9	26.6	25.9	9.34
0.15–0.30 m	13.3	11.7	13.5	13.5	15.8	15.7	16.3	13.4	13.6	3.44
0.30–0.60 m	8.8	7.8	9.4	9.4	8.5	8.9	9.0	7.8	8.7	NS
Total N, mg kg^{-1}										
0–0.15 m	1264	1396	1368	2090	2563	1722	2257	2112	2049	494
0.15–0.30 m	1209	986	986	1291	1278	959	1479	1146	1097	242
0.30–0.60 m	806	806	819	868	896	855	889	938	799	121
$NaHCO_3$-extractable P, mg kg^{-1}										
0–0.15 m	20	22	74	113	121	62	141	179	94	38
0.15–0.30 m	3	4	23	32	60	92	137	111	67	44
0.30–0.60 m	2	3	3	13	17	38	53	13	10	19
0.60–0.90 m	3	2	2	9	6	9	18	8	3	8
Exchangeable K, mg kg^{-1}										
0–1.8 m	354	359	347	491	495	519	646	545	471	98
1.8–3.6 m	245	238	197	242	237	332	256	221	250	NS
Exchangeable Na, mg kg^{-1}										
0–1.8 m	124	159	140	175	169	195	231	224	214	NS
1.8–3.6 m	170	198	178	144	166	196	235	223	187	NS
Exchangeable Mg, mg kg^{-1}										
0–1.8 m	579	538	558	616	589	581	640	621	573	NS
1.8–3.6 m	355	333	357	430	342	383	379	379	330	NS

† FLW rate Mg ha^{-1} and number of applications.
‡ Determination not made.

and the values obtained for 134/5, 268/5, and 536/1 (5 to 6%) compared to that obtained for 536/3 (2.1%) indicate that the samples analyzed for 22/13 or 67/13 and for 536/3 may not have been truly representative of the plots. Mathers and Stewart (1984) measured retention of applied DM on the same plots in 1982 and reported values ranging from about 2% on 536/1 to over 8% on 67/11.

Calculated proportions of applied N remaining in the soil ranged from 47% on 22/13 to about 5% on 134/5. Values for 67/13 (23%) and for 268/5 and 536/1 (14 and 13%) indicate that values for 22/13 and 134/5 may be too high and too low, respectively. The close correlation between OM and total N in the 0- to 0.15-m-soil depth (r = 0.95) indicates that the inconsistencies in the OM and total N data are probably not due to analytical error.

Nitrate N levels in the 0- to 1.8-m-soil depth ranged from 92 kg ha^{-1} on CHK to 404 kg ha^{-1} on 536/3 where 1608 Mg ha^{-1} of FLW had been applied. Levels in the 1.8- to 3.6-m-soil depths were about one-half those in the 0- to 1.8-m depths except on CHK where the 1.8- to 3.6-m depth contained about 20% of that in the 0- to 1.8-m depth.

Nitrifiable N in the 0- to 0.15-m-soil depth was closely associated with OM (r = 0.88), total N (r = 0.93), and with NO_3^--N (r = 0.95) in the 0- to 1.8-m depth. Effects of FLW on N_0 were more consistent than they were on OM and total N. The potentials emphasize the effects of recency of waste applications on N availability. Treatments 22/13, 134/5, and 536/1 had similar N_0 values even though 134/5 and 536/1 had received more than twice as much FLW as 22/13. Also, treatments 67/13, 268/5, and 536/3 had similar N_0 values even though the two latter treatments had received much more FLW. While comparison of 22/13 and 67/13 indicates that the lower application rate resulted in a higher proportion of the applied N being retained as N_0, comparison of 134/5, 268/5, and 536/1 indicates that increases in N_0 were proportional to amounts of FLW applied. Thus, if the lower rate was more efficient when applications were recent, that advantage was lost with time.

Proportions of P applied in FLW to $NaHCO_3$-extractable P ranged from 8.1% on 67/13 to 18.5% on 22/13. The reason for the difference between the two treatments is not readily apparent, however, it is possible that where the higher rate of FLW was applied, a greater proportion of the applied P remained in organic forms. Mathers and Stewart (1984) reported recovering 11 and 8% of applied P on 22/11 and 67/11, respectively. Recency of application of FLW did not affect recovery of applied P as $NaHCO_3$-extractable P. Among treatments that received all of their FLW during the first 5 yr of the study, proportions of applied P recovered as $NaHCO_3$-extractable P ranged from 10.6 to 14.9%. On the NPK treatment, about 22% of applied P was recovered as extractable P while on treatments that received FLW, an average of 13% of applied P was recovered. Mathers and Stewart (1984) recovered 12% of applied P on the NPK treatment and on the FLW treatments.

Exchangeable K was increased on all treatments that received FLW but was not measurably affected on the NPK treatment. Since exchangeable Na and Mg were not affected by FLW applications, those elements must have been leached or held in forms insoluble or slightly soluble in NH_4OA_c. The Na probably was leached from the soil profile but leaching of the divalent Mg ion is much less likely. If these elements had remained in the soil and were soluble in the extractant, amounts extracted should have been increased significantly by application of up to 7560 kg Na and 8040 kg Mg ha^{-1}. Mathers et al. (1973) reported that FLW contains 7.4 g kg^{-1} Na and 5 g kg^{-1} Mg.

Sugarbeet Yield and Quality

The subplot treatments (0 and 134 kg N ha^{-1}) did not affect sugarbeet yields but affected certain quality factors. Since there were no significant main plot-subplot interactions, main plot and subplot treatment effects will be discussed separately except in instances in which interactions might have been expected.

All treatments that had received FLW produced significantly higher root and sucrose yields than those that had not (Table 3). All treatments with FLW produced statistically similar sucrose yields but 134/5 produced lower root yields than 67/13, 268/5, and 536/3. The higher sucrose content in sugarbeets on 134/5 compensated for the lower root yields. Among treatments that did not receive FLW, N and NPK produced higher root and sucrose yields than CHK. Applied N did not affect root and sucrose yields (average yields for the two treatments were almost identical). However, with CHK and NPK treatments, definite trends toward yield increases from applied N were observed. Root yield increases from the N treatment were 17 and 8% on CHK and NPK, respectively. Respective increases in sucrose yields were 16 and 6%.

Nitrate N levels in the 0- to 1.8-m-soil depth were similar on the treatments that had not received FLW but the treatments that had received N previously contained more NO_3^--N in the 1.8- to 3.6-m depth (Table 2). The 17 and 16% increases from applied N on CHK compared to the smaller response on NPK and no response on N indicate that sugarbeets may have extracted N from below the 1.8-m-soil depth. The reason for 134/5 producing lowest sugarbeet yields among treatments that had received FLW is not known. The comparatively low soil NO_3^--N level suggests that the supply of available N may have limited yields, however, if that had been the case, applied N should have increased yields.

Quality Factors

Sucrose concentrations of the sugarbeets ranged from 111.6 to 135.5 g kg^{-1} (Table 3). They were inversely related to soil NO_3^--N contents (Table 2). The three treatments that had not received FLW produced sugarbeets with higher sucrose contents than those that had received FLW. Among treatments that had received FLW, sucrose concentrations ranged from 111.6 to 130.7 g kg^{-1}. Although applied N did not significantly affect sucrose concentration, there were trends toward decreases in concentrations with N application on most main plot treatments.

Concentrations of Na, No_3, and amino-N were low-

Table 3. Sugarbeet root yields, sucrose yields and quality factors (sucrose concentration, nitrate grade, and amino-N, Na, and K concentrations, and sucrose loss to molasses) as affected by FLW and fertilizer treatments.

	Treatments									
	CHK	N	NPK	22/13†	67/13	134/5	268/5	536/3	536/1	LSD (0.05)
Beet yield, Mg ha^{-1}										
−N‡	54.9	72.5	68.1	85.9	93.7	81.5	91.5	93.4	90.8	8.5
+N	64.3	70.1	73.5	88.9	89.8	83.8	95.4	91.6	83.6	8.8
Sucrose yield, kg ha^{-1}										
−N	7430	9760	9180	10470	10720	10650	10940	10840	11450	742
+N	8600	9490	9750	10750	10370	10620	11050	10940	10350	1019
Sucrose concentration, g kg^{-1}										
−N	135.5	134.6	135.0	122.4	114.5	130.7	119.6	116.1	126.1	7.6
+N	133.8	133.5	132.6	120.7	115.5	127.1	111.6	119.4	123.9	6.8
Nitrate grade§										
−N	3.93	4.07	3.87	4.47	4.93	4.20	4.87	5.00	4.13	0.34
+N	4.00	4.00	4.07	4.63	5.07	4.10	5.00	4.87	4.30	0.36
Amino-N, mg kg^{-1}										
−N	282	363	311	404	487	362	458	450	363	95
+N	330	346	323	445	515	362	464	476	395	80
Na in beets, mg kg^{-1}										
−N	442	509	439	741	892	523	762	857	555	159
+N	516	529	483	763	938	543	845	802	650	167
K in beets, mg kg^{-1}										
−N	2228	2145	2288	2236	2334	2200	2290	2247	2275	NS
+N	2126	2163	2214	2216	2334	2158	2250	2286	2301	NS
Sucrose loss to molasses, g kg^{-1}										
−N	13.4	14.5	13.9	16.4	18.5	14.7	17.4	17.6	15.1	2.1
+N	14.0	14.4	14.0	17.0	19.1	14.7	17.7	17.8	16.0	1.9

† FLW rate Mg ha^{-1} and number of applications.
‡ +N = sugarbeets fertilized with 134 kg N ha^{-1}; −N = no N applied on sugarbeets.
§ 2 + 3.4 (log mg L^{-1} nitrate electrode response − 1).

est in sugarbeets grown on treatments that had not received FLW and highest on those that had received large quantities of waste. They were directly related to soil NO_3^--N levels and inversely related to sucrose content of the sugarbeets. Applied N caused significant increases in concentrations of Na, amino-N and NO_3 in the sugarbeets. Potassium concentrations in the sugarbeets were not significantly affected by the FLW treatments nor by applied N. Neither the increased K in the soil from the FLW nor the increased soil NO_3^--N affected K content of sugarbeets. This is not in keeping with results reported by Carter (1986) who found uptake of Na and K by sugarbeets to be related to N uptake.

Losses of sucrose to molasses, which are based on Na, K, and amino-N concentrations in the sugarbeets, were higher on treatments that had received FLW than on those that had not. Like Na and amino-N concentrations, they were directly related to soil NO_3^--N levels.

Sugarbeet-Soil Analyses Relationships

Correlations between sugarbeet yield and quality factors and soil analyses values are given in Table 4. Yield and quality factors are from subplots that did not receive N. Correlation coefficients between nitrifiable N and yield and quality factors were always as high or higher than those between NO_3^--N, OM, and total N and the sugarbeet factors. This indicates that N_o in the 0- to 0.15- or 0- to 0.6-m depths were as good indicators of the yield and quality factors as the other measurements. It is not surprising that N_o was

Table 4. Simple correlations between sugarbeet yield and quality factors and several indicators of soil N availability at various depth in a clay loam soil.

	Nitrate N	Nitrifiable N		Organic Matter		Total N	
	0–1.8 m	0–0.15 m	0–0.6 m	0–0.15 m	0–0.6 m	0–0.15 m	0–0.6 m
Root yield	0.76*	0.88**	0.92**	0.84**	0.73*	0.92**	0.65*
Sucrose yield	0.54	0.71*	0.78*	0.70*	0.61	0.77*	0.39
Sucrose concentration	0.94**	0.99**	0.95**	0.89**	0.77*	0.95**	0.91**
Nitrate grade	0.96**	0.97**	0.95**	0.80**	0.69*	0.87**	0.90**
Amino-N	0.90**	0.99**	0.97**	0.87**	0.74*	0.92**	0.82**
Na in beets	0.97**	0.98**	0.91**	0.84**	0.71*	0.90**	0.93**
K in beets	0.51	0.47	0.41	0.70*	0.74*	0.62	0.63
Sucrose loss to molasses	0.95**	0.99**	0.95**	0.89**	0.76*	0.94**	0.95**

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

as good an indicator as OM and total N since it is dependent on those two quantities but its equality to NO_3^--N was not expected considering that NO_3^--N is a direct measure of soluble N and NO_3^--N levels were high due to the fallow period preceding the growing of sugarbeets. Nitrifiable N, as determined in this study, deserves further evaluation as an indicator of N supplying capacity of the soil.

DISCUSSION AND CONCLUSIONS

The soil analyses show that portions of the N, P, and K applied in FLW accumulated while Na and Mg were leached from or held in unextractable forms in the root zone of an irrigated Pullman clay loam. Where excessive rates of FLW were applied, nitrates were leached from the root zone as evidenced by previous research (Mathers and Stewart, 1984) and by disappearance of N. Excessive applications of FLW may cause salt or ammonia damage to seedlings of crops planted soon after application as reported by Mathers and Stewart (1984), however, our soil analyses did not indicate any lasting deleterious effects on soil productivity.

Root and sucrose yields of sugarbeets were increased by the residual effects of the FLW applications. Failure of the treatments that did not receive FLW but received N to yield as much as those that received FLW indicates that the sugarbeets responded to effects of FLW other than the supply of N, P, and K. Feedlot waste increased soil OM and it has been shown to increase aggregate stability (Elson, 1941, 1943), increase water holding capacity and decrease evaporation rate (Unger and Stewart, 1974), increase water infiltration (Mathers et al., 1977; Mazurak et al., 1955; and Swader and Stewart, 1972), decrease bulk density and increase hydraulic conductivity (Mathers and Stewart, 1981). These effects contribute to improved soil tilth and are generally regarded as beneficial to plant growth, however, the literature does not indicate any effects of manure on sugarbeet growth beyond supplying plant nutrients. Halverson and Hartman (1975) found that application of 22.4 Mg ha^{-1} of barnyard manure in alternate years produced a higher sucrose yield than any other treatment without any apparent accumulation of soil NO_3^--N and concluded that barnyard manure could be utilized to produce quality sugarbeets and dispose of a waste and potential pollution product. Gardner and Robertson (1947) found N and P fertilizers and manures to be equal in their effects on sugarbeet yields.

Sugarbeet root quality decreased when soil nitrate levels were excessive. The fallow period between the last grain sorghum crop and sugarbeet planting allowed a greater accumulation of soil nitrates than would have accumulated during a short fallow period, thus the effects of specific waste treatments on sugarbeet quality probably were exaggerated. Among the treatments that received FLW, 134/5 produced sugarbeets with the highest sucrose concentrations, lowest impurity indexes, and sucrose yields equivalent to the other FLW treatments. That treatment also had the lowest soil nitrate level at planting. This one year's data indicate that 200 kg of NO_3^--N ha^{-1} in the 3.8-m profile at planting were sufficient for maximum yields of good quality sugarbeets.

Our results indicate that the use of FLW in sugarbeet production on Pullman soils merits further study. If it has beneficial effects beyond supplying plant nutrients, there would be an incentive to use a material that is now a surplus waste product.

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